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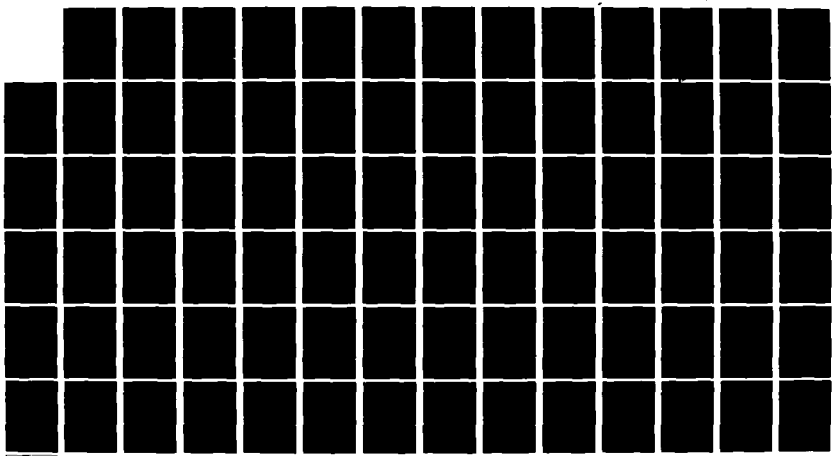

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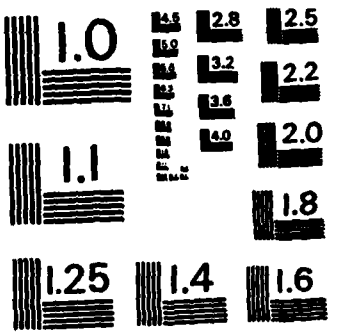

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THE INFLUENCE OF CHANNEL REGULATING STRUCTURES ON FISH AND WILDLIFE HABITAT

A REPORT SUBMITTED TO

U. S. Army Corps of Engineers
St. Louis District

PREPARED BY

The Institute of River Studies
University of Missouri-Rolla
Rolla, Missouri 65401
Roger H. Smith and Glendon T. Stevens, Jr.

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The Missouri Department of Conservation
Fish and Wildlife Research Center
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Columbia, Missouri 65201
Timothy B. Grace and A. Stephen Weithman

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The purpose of this study was two-fold:
1. To evaluate aquatic habitat diversity, accretion patterns, flow patterns and bed material gradation existing around in-place channel regulating structures at different locations and of varying design;
2. To recommend, where possible, data needs and structure modifications which will maintain or improve existing fish and wildlife habitat while preserving the geometry needed to maintain an acceptable navigation channel.

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ABSTRACT

INTRODUCTION

The Army Corps of Engineers is charged by the Congress to provide and maintain navigation channels to sustain the requirements of commercial river transportation. In carrying out this mandate, the Corps has constructed a system of river control structures. Under the Water Resources Development Act of 1976 (PL 94-587) the Corps has been authorized to study problems such as the one addressed herein. With this in mind the Regulating Structures and Fish and Wildlife work groups of the Great River Resource Management Study determined that a study was warranted, as a means of establishing the extent of effect that stabiliziation of the Middle Mississippi River has had on fish habitat. This is a formidable task which was made more difficult by virtue of the lack of historical data on fish habitat and water quality. Because of this deficiency and in order to arrive at meaningful conclusions within the ~~constraints of limited time and resources,~~ the study focused on measuring existing conditions and fish habitat around a selected group of river regulating structures. ~~Therefore,~~ Prototype data was collected at dikes of varying design and location. Such data was subsequently used to determine specifics in regard to the fish habitat that exists around each type of dike analyzed.

PURPOSE

The purpose of this study is two-fold:

1. To evaluate aquatic habitat diversity, accretion patterns, flow patterns and bed material gradation existing around in-place channel regulating structures at different locations and of varying design; AND
2. To recommend, where possible, data needs and structure modifications which will maintain or improve existing fish and wildlife habitat while preserving the geometry needed to maintain an acceptable navigation channel.

ENGINEERING STUDY

Eight rock dikes located within the reach of the Middle Mississippi River between river miles 95 and 115 were selected for intensive study. Five of the eight structures are located on the left ascending bank (114.0L, 113.9L, 113.5L, 103.2L, 102.2L) and three on the right ascending bank (103.3R, 100.1R, 98.9R). Five of these eight dikes are notched. River stage, velocity, bed configuration and sediment data were collected downstream of each of these eight dikes four different times within a 140-day study period.

Low water aerial photographs for the study reach for the years 1965, 1970 and 1980 were analyzed for changes in water surface area and wetted edge downstream of the dikes.

BIOLOGICAL STUDY

The species composition and abundance of fish and aquatic macroinvertebrates at the eight dikes listed above were studied over a 186-day period. Data on fishes were obtained by electrofishing and with three kinds of nets during four different sampling periods. In addition, measures of water quality were monitored and qualitative observations of wildlife were recorded during the study. A literature review of the effects of channel regulating structure design on fish and wildlife and their habitat was conducted.

SUMMARY AND RECOMMENDATIONS

The scope of study limited data collection to four sampling periods during the study at eight dikes pre-selected from the study reach of the Middle Mississippi River. Therefore, any results or conclusions drawn from the limited amount of data collected must be qualified accordingly.

The bed samples collected during this study indicate that the bed material deposited downstream of notched dikes contains a higher percentage of sand than the material deposited downstream of other dikes. The addition of a trail to a notched dike, according to the data collected in this study, will reduce the percentage of sand in the bed downstream of the structure. As a result, this is a modification that should be investigated further.

The suspended sediment samples collected during this study show that the suspended sediment concentration has been greatly reduced as compared to 1937 data. This would indicate a potential decrease in the rate of land accretion around regulating structures, thus indicating a potential decrease in the rate of loss of fish and wildlife habitat.

Water surface area and wetted edge data obtained from the aerial photographs of the study reach were analyzed. Three of the four sub-areas has a loss rate between 1970 and 1980 that was less than the loss rate between 1965 and 1970. These results are in agreement with the suspended sediment data analysis.

The data collected during this study indicate that the location of a structure, with respect to the thalweg, influences the gradation and accretion pattern associated with channel regulating structures more than the type or location of modification.

The point velocity data collected during this study indicate that there is a correlation between the flow pattern downstream of regulating structures and the type of accreted material and accretion pattern.

Diversity of aquatic macroinvertebrates, and to a lesser extent fish communities, for this study, was found to be greater at notched dikes than at unnotched dikes. This is believed to result from the greater variety of habitat created below notched dikes. In other words, suitable habitat was available to more species. The length-frequency

analyses of fish showed that the dissimilar habitat conditions at conventional and modified regulating structures suited different life stages of fish. Selective modification of channel regulating structures in the future on the Middle Mississippi River would make additional, diverse habitats available to greater numbers of the resident fauna.

Analysis of the data collected during this study period indicates that fish abundance at conventional and modified dikes was not significantly different; however, aquatic macroinvertebrates were more abundant at notched dikes. The similar catch rates of fish at each type of dike are believed to be a result of high water and because many of the species are extremely mobile. Future research should be directed towards species of fish (e.g., gizzard shad, carp, bigmouth buffalo, channel catfish, blue catfish, flathead catfish, and freshwater drum) that are especially important to the recreational and commercial fisheries.

Integrated, long-term, physical and biological studies of channel regulating structures in the Middle Mississippi River should be conducted to gain a better understanding of the relationship between the habitat and its inhabitants. Future research should attempt to subdivide the habitat at a dike (e.g., dike tip, dike proper, size of rock, pilings, notch, scour hole below a notch, trail dike, revetment, sand shoreline, mud shoreline, etc.) and determine the value of each subhabitat to the fishery. Future dike construction and maintenance work could then accommodate desirable subhabitats.

The previous findings appear to justify the extension of this investigation into a second phase. This seems warranted in light of the fact that many serious questions remain in regard to the impact of channel regulating structures on fish and wildlife habitat. It is believed by the investigators that a second phase of effort might result in the elimination of some questions and assumptions which could not be addressed in this effort.

Long-term trends in channel geometry and aquatic habitat cannot be established without further investigation. The response of the system to annual variations of flow is needed and can be determined with yearly visits over a period of time.

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GLOSSARY OF TERMS

Dike (wing dike)	-	a structure that extends from the shoreline at an oblique or perpendicular angle to the current.
L-head dike	-	a dike with a trail.
Trail	-	a low dike extension downstream of the tip of the dike parallel with the direction of flow.
Notch	-	a gap or opening in the crest of a dike.
Low sill extension	-	a low dike extension.
Habitat diversity	-	The amount, kind, and mix of habitat conditions necessary to support a variety of healthy populations of fish and wildlife.
Wetted edge	-	The amount of shoreline habitat, including islands.

I. DESCRIPTION OF STUDY

A. GENERAL INTRODUCTION

Since earliest times man's need for a supply of fresh water, food, clothing and an easy avenue of transport has dictated the site of his home. Consequently, the development of community life brought with it the need for navigation, channel maintenance, preservation of fish and wildlife habitat, planning for water supply and the beginning of river engineering. Although little is documented regarding the engineering art involved, the remains of irrigation, water supply and navigation channel improvement structures are among the earliest monuments of civilization.

The Army Corps of Engineers is charged by Congress to provide and maintain a navigation channel that will meet the needs of commercial river transportation. In carrying out this charge the Corps has developed and constructed a system of channel regulating structures to insure navigation in inland waterways. Because channelization has changed the riverine habitat, the Regulating Structures and Fish and Wildlife Work Groups of the Great River Environmental Action Team determined that a study was needed to assess present types of aquatic habitat associated with dikes on the Middle Mississippi River.

This study was conceived as a means of establishing the extent of effect that channelization of the Middle Mississippi River has had on fish and wildlife habitat. This task is made more difficult by the lack of historical data on fish and wildlife communities prior to navigation

channel improvements. Because of the lack of historical data this study was focused on measuring existing geometric conditions and types of aquatic habitat around in-place structures.

Before channel modification to improve navigation, the Mississippi River was a maze of log jams, root wads, chutes, side channels and sandbars. Habitat of this nature was changing because of the dynamic nature of a meandering, natural river channel. This constantly changing river habitat has been replaced by a river which at present is controlled by channel regulating structures that are relatively permanent. With proper design and maintenance these structures can provide a stabler navigation channel that should accommodate a more productive aquatic habitat.

It would appear plausible to make the assumption that water quality changes have effected changes in the aquatic environment as much as those caused by regulating structures. However, aquatic flora and fauna have changed over time in accordance with the constraints of the aquatic environment.

B. REGULATING STRUCTURE DEVELOPMENT

Navigation channel improvements on the Mississippi River began in 1824 when the U.S. Army Corps of Engineers was charged with the task of snag removal (Munger 1976).

The first navigation channel improvement structure (dike) on the Middle Mississippi River was built in 1838 by Lieutenant Robert E. Lee at Bloody Island near St. Louis, Missouri (Dobney 1977). Between that date and the present, approximately 1,076 such regulating structures have been constructed on the Mississippi River between Saverton, Missouri and Cairo, Illinois. A variety of materials (wood, concrete and stone) have been used over the years to construct regulating structures.

According to Simons (1974), the geometric properties (river length, average width, average water surface area, and area of islands) of the Middle Mississippi River at the present are very similar to that of the early 1800's. This has been accomplished through use of bank stabilization structures (revetments) and navigation channel regulating structures (dikes).

The first regulating structure modification was made in 1972 at Dike 122.6L. This modification was proposed as an attempt to reduce land accretion and increase diversity of aquatic habitat. Since that date in excess of 75 structures have been modified, in various ways, between river mile 0 and 125. Some dikes have been modified by lowering the elevation of the river end. However, most of them (64) have been modified by notching. Trails, another type of modification, have been added to some dikes for navigation purposes.

Any type of modification at most locations should change the accretion pattern and aquatic habitat that otherwise would exist around a river regulating structure.

C. STUDY REACH

The reach of the Middle Mississippi River between river miles 95 and 115 (near Chester, Illinois) was selected by the GREAT III Work Groups as the segment of the river to be utilized in this study. A plan view of the study reach is depicted in Figure 1. There are 102 channel regulating structures within this reach of river. The types of modification found within this reach are notches, trails and low sill extensions. Thirteen of these structures have been modified by notching or low sill extension as an attempt to reduce land accretion and thus provide a diversity of aquatic habitats.

D. STUDY DIKES

Eight of the 102 dikes in the study reach were selected for intensive study. These eight dikes were selected based upon their physical characteristics (Table 183) and location in the river (Figure 1). All eight dikes are located in the main channel border (Sternberg 1971) of the river.

The eight dikes selected for study are 114.0L, 113.9L, 113.5L, 103.3R, 103.2L, 102.2L, 100.1R and 98.9R. Five of these eight structures are located on the left "L" ascending bank and three are located on the right "R" ascending bank. Five of these channel regulating structures have been modified by notching to provide a change in aquatic habitat and land accretion patterns. The construction history of each study dike is provided in Figures 7-14.

Dikes 114.0L, 113.9L and 113.5L are located (Figure 1) such that they should be subjected to very similar flow conditions. The location of each of the other study dikes is such that they should be subjected to dissimilar flow conditions. Therefore, the accretion patterns found around dikes 114.0L, 113.9L and 113.5L should be similar. The accretion patterns found around each of the other study dikes should be dissimilar.

The gradation of the bed material located downstream of each of the study dikes should be different because of the varying flow conditions to which they are subjected and the various design modifications of each.

The type and abundance of fish and aquatic macroinvertebrates found around each of the study dikes should be different because of the flow

conditions and the bed material gradation variations that should be found at each dike.

A description of the site at each study dike is presented below along with a list of photographs that depict the site. When dikes are repaired and their length extended, the extension is aligned such that it is perpendicular to the direction of flow. These alignment changes are shown in Figures 7-14 and Photographs 1-70.

Dike 114.0L (Photos 5-9)

Approximately 150 feet of the bank immediately downstream from this dike have been revetted to prevent erosion. The remains of the old pile dike can be seen immediately downstream of this dike. An extensive sand-silt flat is exposed downstream of this dike during low river stages. It is similar to the exposed area downstream of dike 113.9L, and extends outward from shore almost to the tip of the dike for much of the distance between these two dikes.

Dike 113.9L (Photos 7-14)

Dike 113.9L is similar in shape, placement of notch, and channel alignment to dike 113.5L (located immediately downstream). A few remnants of an old pile dike remain along this dike. Much of the area below this dike is exposed as sand-silt flats during low river stages. This exposed area, from shore to almost the end of the structure, extends from dike 113.5L to a short distance downstream of dike 113.9L.

Dike 113.5L (Photos 15-18)

The remains of the old pile dike can be seen immediately downstream of much of the shoreward half of dike 113.5L. A mud bank with large

trees overhanging the river is found among much of the shoreline downstream of this dike. An extensive mud flat is exposed downstream from this dike during low river stages, extending out from shore almost to the tip of the dike.

Dike 103.3R (Photos 19-28)

This structure is level with the high bank at its base and slopes downward toward the channel. The bank below this dike is moderately sloped and lined with rock. Mud flats extend quite some distance channelward from this bank during low river stages.

Dike 103.2L (Photos 29-37)

The trail on this dike is usually under water. Dike 103.2L is a nearly level structure. The bank below this dike is quite steep and at places has undercut trees. Unusually deep water is found immediately downstream from this dike.

Dike 102.2L (Photos 38-48)

Dike 102.2L has a single notch midway along its length. This dike is quite high at its base and gradually slopes downward toward the tip. The bank below this dike slopes gradually and consists primarily of sand. A large sand bar is exposed downstream during low river stages.

Dike 100.1R (Photos 49-64)

The trail on this dike is a low structure and is usually under water. Dike 100.1R is high at its base and gradually slopes downward toward the tip. A relatively high, sand-silt island occurs downstream of the

distal one-half of the dike. Old pilings remain immediately downstream of the notch. The bank downstream of this dike slopes gradually.

Dike 98.9R (Photos 65-70)

Dike 98.9R has two notches, a shallow notch near its base and a very large notch approximately halfway between the midpoint and tip of the dike. This structure is level with high bank at its base and slopes gradually downward toward the tip. Remnants of an old pile dike remain immediately downstream of the large notch. Bank erosion has created a shallow round out with undercut trees below the base of the dike.

E. ORGANIZATIONS

This study was completed through a joint effort by the Institute of River Studies at the University of Missouri-Rolla, the Missouri Department of Conservation, and the St. Louis District Corps of Engineers.

The Institute of River Studies was awarded the GREAT III contract and the responsibility of directing the study, assimilating the data collected, and preparing the final report. Institute personnel collected the field data required for the engineering phase of the study.

The Missouri Department of Conservation, subcontracting with the Institute of River Studies, collected and analyzed the data required to complete the biological phase of the study and prepared a draft report.

The St. Louis District Corps of Engineers furnished aerial photographs, dike history, stage and discharge data as required to complete the study. They assisted in locating dikes that had been modified. The Corps furnished a knowledgeable river engineer to assist in data collection. The Corps arranged a boat trip for interested Work Group members to aid in the selection of the study dikes.

II. PURPOSE

The purpose of this study is two-fold:

1. To evaluate fish habitat and sediment characteristics extant around river control structures of varying design which are in place.

2. To recommend, where possible, data needs and dike modifications which could serve to optimize aquatic habitat while preserving the geometry of the navigation channel.

III. OBJECTIVES

The objectives are to conduct a study which will generate data that can be utilized in the design of dikes to preserve the navigation channel geometry and provide a diversity of aquatic habitats. This can be accomplished only through a joint effort between river engineers and biologists. To create a design acceptable to both, a compromise is required. The ultimate design must strike a balance between both groups.

All dikes, regardless of design, are sediment traps because of the slack water area created downstream of each. Certain dike fields, regardless of design, have a higher rate of accretion than others. The state-of-the-art of dike design is such that, under certain flow conditions, dikes can be designed to encourage predetermined gradation and accretion patterns. Therefore, the task at hand is to determine the gradation of bed material and accretion pattern that will provide maximum aquatic habitat while maintaining adequate navigation.

IV. ENGINEERING STUDY

A. DATA COLLECTION AND METHODOLOGY

Phase 1: Preliminary Dike Analysis

According to the scope of work under Phase I of this study, the following dikes were selected for intensive study:

Dike Number	Description
98.9R	Notched Straight dike (2 notches)
100.1R	Notched, trail
102.2L	Notched, angled (below side channel entrance)
103.2L	Solid, trail
103.3R	Angled, sloped, solid
113.5L	Notched, angled
113.9L	Notched, angled
114.0L	Solid, flat, straight

The phase construction history for each of these eight dikes was compiled and is displayed in the Appendix, Figures 7-14. Because of the dynamic behavior of the Mississippi River, the geometric properties of these dikes may have changed since construction.

The scope of work required the utilization of aerial photographs to determine (for different time periods) the water surface area and wetted edge between a line connecting the exposed riverward end of adjacent dikes and the exposed bankline. This was done with the aid of polar and scalar planimeters for all dikes within a reach that extended from one mile upstream to one mile downstream of each of the study dikes.

The study dikes are located such that application of these criteria produced four sub-areas. Sub-Area 1 (112.2L to 115.0L) contains dikes 114.0L, 113.9L, and 113.5L. Sub-Area 2 (101.4L to 103.8L) contains dikes 103.2L and 102.2L. Sub-Area 3 (102.4R to 104.4R) contains dike 103.3R. Sub-Area 4 (97.5R to 101.0R) contains dikes 100.1R and 98.9R. Plan views of the four sub-areas for the three dates selected are depicted in the Appendix, Figures 2 through 6.

The procedural concept of determining water surface area and wetted edge around dikes from aerial photographs for comparative purposes is sound provided the aerial photographs have the same scale and were taken when river stages were comparable.

The available low water aerial photographs supplied by the Corps of the study reach were reviewed and the following three sets were selected for use in determining the data required to complete this study.

Date	Stage Ft. (St. Louis gage)
1. August 2 and 3, 1965	4.6 and 4.7
2. January 30, 1970	4.8
3. July 15, 1980	5.0

Checking the scale of each of the three sets of aerial photographs revealed the scale of those taken in 1965 to be 1 inch = 2,000 ft. and those made in 1970 and 1980 were at a scale of 1 inch = 1,000 ft. Utilizing ground control to check the scales proved that the 1970 and 1980 photographs had different scales. Thus, there is distortion in photographs. The tracings made from the aerial photographs when overlain will show this distortion. Therefore, the data obtained from these aerial photographs are questionable and should be dealt with accordingly.

Phase 2: Intensive Study

A total of five field visits were made to each of the eight study dikes. The first, completed in April of 1981, was made to establish the five ranges at each of the study dikes. A baseline was surveyed such that permanent stations, marking the five ranges, were located on high bank. The stations were surveyed so that the ranges would be parallel to the riverward section of the respective dike. The ranges at dikes 114.0L, 113.9L, 113.5L, 103.3R, 103.2L and 102.2L, were established at a distance of 100, 300, 500, 700 and 900 ft. downstream from and parallel to the riverward section of each. The ranges at dike 100.1R were established at a distance of 100, 300, 500 and 700 ft. downstream and 176 feet upstream from and parallel to the riverward section of the dike. The ranges at dike 98.9 were established at a distance of 100, 300, 500 and 700 ft. downstream and 200 ft. upstream from and parallel to the riverward section of the dike. A plan view of each dike showing the location of each range is included in the Appendix as Figures 16-23. The remaining four field trips were made in May, June, September and October of 1981 for purposes of collecting the data required to complete the engineering phase of this study.

Soundings of the river bed were made at each range with the aid of a Raytheon recording fathometer and a Motorola mini-ranger. The boat (Photo No. 1), transporting the fathometer and mini-ranger, was kept on a range by a transit located at the proper permanent station. Constant communication was maintained between the boat operator and the transit person by radio to insure that the fathometer was kept on range.

The data collected with the recording fathometer and mini-ranger were utilized in developing the river bed profiles for each parallel range and a two foot interval contour map for the area enclosed by the ranges. The bed profiles (Figures 56-118) and contour maps (Figures 24-55) are located in the Appendix.

The mean velocity measured at 0.6 of the water depth below the surface, and its direction were determined at three different locations on each range. The velocity was determined with an AA Price current meter (Photo No. 2) and its direction with a rotating compass apparatus. The point velocity magnitude, direction and location are shown on Figures 119 through 148 of the Appendix.

Bed samples were collected at two points downstream of each study dike. These samples were collected with a BM 54 grab sampler (Photo No. 4). The location of each sample is shown in Figures 119-148. The bed samples were collected downstream of the notch for all notched dikes and near mid-length for unnotched dikes. The samples were dried and sieved. The results of the sieving can be found in Figures 181-222 and Tables 4-11. A hydrometer analysis (Means & Parcher 1964) was performed on those samples that were 100% silt and clay (100% passed a No. 200 sieve). The results of the hydrometer tests are shown in Table 4-11.

Point suspended sediment samples were collected at two location downstream of each study dike. These samples were collected with a P61 TM sampler (Photo No. 3). They were collected at mid-depth and downstream of the notch for all notched dikes. At unnotched dikes the point samples were collected downstream and near mid-length of the dike. The location of each point sample is shown in Figures 119-148. Each of

the point suspended sediment samples was analyzed using a membrane filter. The results of the analyses are shown in Table 2. Suspended sediment samples were not collected at each dike for every field visit because at times, the magnetic device that opens the sampler valve would not function.

Photographs were taken of each study dike to depict its general condition, orientation, modification and the type of accretion pattern around the dike. These photographs are displayed in the Appendix on pages 227-259.

B. DATA ANALYSIS AND DISCUSSION OF RESULTS

Water Surface Area and Wetted Edge Data

Examination of the data displayed on Figures 2 through 6 will indicate the following:

Sub-Area 1 (mile 112.2 to 115.0) contains study dikes 114.0L, 113.9L and 113.5L. Analysis of the water surface area data for this study area will show that there has been an increase of 12 acres in 15 years, an average rate of increase of 0.80 acres per year. Comparing the 1965 data to the 1970 shows a decrease of 23 acres or a loss rate of 4.6 acres per year. Comparing 1970 with 1980 indicates an increase of 35 acres for an increase rate of 3.5 acres per year. Comparing the 1965 and 1970 wetted edge data shows a decrease of 11,000 ft. which gives a loss rate of 2,200 ft. per year. Comparing the wetted edge for 1970 and 1980 shows an increase of 3,500 ft. for a rate of increase of 350 ft. per year. The 15-year period shows a decline in wetted edge of 7,500 ft. for a loss rate of 500 ft. per yer.

Sub-Area 2 (mile 101.4 to 103.8) on the left ascending bank contains study dikes 103.2L and 102.2L. Comparing the water surface area of 1965 to 1970 reveals a loss of 63 acres for a loss rate of 12.6 acres per year. Comparing the data for 1970 and 1980 reveals a loss of 37 acres for a loss rate of 3.7 acres per year. The 15-year period shows a loss of 100 acres for a loss rate of 6.67 acres per year. The wetted edge for 1965 and 1970 shows a loss of 5,600 ft. for a loss rate of 1,120 ft. per year. Comparing the 1970 and 1980 data shows a loss of 400 ft. for a loss rate of 40 ft. per year. The 15-year statistics show a loss in wetted edge of 6,000 ft., for a loss rate of 400 ft. per year.

Sub-Area 3 (mile 102.4 to 104.4) on the right ascending bank contains study dike 103.3R. Analyzing the water surface area data for the year 1965 and 1970 shows a decrease of 17 acres for a loss rate of 3.4 acres per year. Comparing the 1970 and 1980 data reveals an increase of 2 acres for an increase rate of 0.2 acres per year. The 15-year comparison shows a total loss of 15 acres for a loss rate of 1 acre per year. Comparing the wetted edge in 1965 and 1970 shows an increase of 10,000 ft. for an increase rate of 2,000 ft. per year. Analysis of the 1970 and 1980 data shows a loss of 500 ft. for a loss rate of 50 ft. per year. Analysis of the wetted edge data for the 15-year period shows an increase of 9,500 ft. for an increase rate of 633.3 ft. per year.

Sub-Area 4 (mile 97.5 to 101.0) on the right ascending bank contains study dikes 98.9R and 100.1R. Comparing the water surface area for 1965 and 1970 shows an increase of 68 acres for an increase rate of 13.6 acres per year. Analysis of the 1970 and 1980 data produces a loss of 117 acres for a loss rate of 11.7 acres per year. Comparing the water surface area for 1965 and 1980 shows a loss of 49 acres for a loss rate of 3.3 acres per year. Comparing the wetted edge for 1965 and 1970 shows an increase of 9,000 ft. for an increase rate of 1,800 ft. per year. Analysis of the 1970 and 1980 data shows a loss of 8,800 ft. for a loss rate of 880 ft. per year. The 15-year period shows an increase in wetted edge of 200 ft. for an increase rate of 13.3 ft. per year.

Analyzing the four sub-areas together will show a loss of water surface area of 152 acres for the 15-year study period. This results in a loss rate of 10.1 acres per year. Comparing totals for the four

sub-areas produces a loss in wetted edge of 3,800 ft. for the 15-year period. This produces a loss rate of 506.7 ft. per year.

The Mississippi River is a very dynamic and constantly changing river system experiencing large overbank floods in some years and extreme low flows in other years. In addition, some of the channel regulating structures in place during 1980 were either not present during 1970 or 1965 or were repaired and extended prior to 1980. Therefore, the results shown for the four sub-areas regarding water surface area and wetted edge are not in true perspective and should be qualified accordingly.

Discharge Data

Examination of the discharge data, displayed on Figure 15, will substantiate the following statements. During the period of April 1 through April 10 the ranges at each study dike were established. The discharge of the Mississippi River at Chester, Illinois during this period varied from a low of 92,800 cfs to a high of 138,000 cfs. The discharge of the river varied between 215,000 cfs and 244,000 cfs during the period May 30 through June 2 when the first set of data was gathered. The discharge at Chester was 539,000 cfs on the 22nd of May. Therefore, the discharge had dropped 295,000 cfs in the eight days preceding data collection. During the four days of data collection the discharge reduced 29,000 cfs. On June 13 the discharge was 155,000 cfs; therefore, it decreased 60,000 cfs in eleven days after the data were collected.

The second data collection period was June 16 through June 19. During this period the discharge increased 62,000 cfs (from 212,000 cfs to 274,000 cfs). An increase of 57,000 cfs occurred during the three

days preceding this visit. On June 24, the discharge reached 427,000 cfs; thus, an increase of 153,000 cfs was observed in five days after sampling.

During the period September 14 through 18, the third data collection period, the discharge varied from 171,000 cfs to 143,000 cfs, a decrease of 28,000 cfs in four days. On September 5 the discharge was 228,000 cfs, thus, a decrease of 57,000 cfs occurred in nine days preceding the data collection period. The discharge of the Mississippi receded 40,000 cfs in three days following data collection.

From October 13 through 17, the fourth data collection period, the discharge varied from 128,000 cfs to 164,000 cfs. The discharge increased 36,000 cfs over a four-day period. On October 8, the discharge was 121,000 cfs; therefore, the discharge increased 7,000 cfs during the four days preceding data collection. The river continued to rise for two days after the fourth visit, reaching 192,000 cfs and then started a gradual decline.

Suspended Sediment Data

The results of suspended sediment analyses are shown in Table 2, page 261 of the Appendix. The location of each sample is also listed in Table 2 and shown in Figures 119-184 of the Appendix.

Comparing the total concentration of the suspended sediment samples collected during this study shows an increase in concentration with flow. As expected, all samples collected during the same period of time or at the same flow were, for all practical purposes, equal. No significant difference can be found in the suspended sediment concentration between

modified and unmodified dikes. It appears from the data that suspended sediment concentration decreases between dikes in a downstream direction. The average concentration of those samples collected in June, 1981 was 132 PPM. The average concentration of those suspended sediment samples collected in September, 1981 was 113 PPM. The average concentration of the suspended samples collected in October, 1981 was 98 PPM.

Comparing the suspended sediment concentration of the samples collected for this study with those by E. W. Lane (Lane & Kennedy 1939) as reported by Munger (Munger 1976) at Chester, Illinois (mile 109.9) in 1937 shows a large reduction in suspended sediment load. In June of 1937 (discharge 319,000 cfs) the suspended sediment concentration was 951 PPM. The discharge in June of 1981 was 250,000 cfs and the concentration was 132 PPM. In September, 1938 (discharge 278,000 cfs) the suspended sediment concentration was 1,326 PPM: however, in September of 1981 (discharge 160,000 cfs) the concentration was 113 PPM. In August of 1937 (flow 115,000 cfs) the sediment concentration was 4,412 PPM, but in October of 1981 (flow 140,000 cfs) the suspended sediment concentration was 98 PPM.

Bed Sediment Data

A bed sample was collected for each sampling period downstream of each study dike on ranges 1+00 and 3+00 with one exception. At Dike 103.2L one sample was collected on range 7+00 and one on range 9+00. The exact location of each sample is shown in Figures 119-184, and in Table 3, pages 262-263 of the Appendix. The results of the sieve analysis (Means & Parcher 1964) are shown in Figures 181-222, and in Tables 4-11 of the Appendix. All samples that had a gradation such that 50% or more

passed a No. 200 sieve were prepared and tested with a hydrometer. The results of the hydrometer tests (% clay) are shown in Tables 4-11. The diameter of the grain, at which 65% (D_{65}) and 50% (D_{50}) of the sample was finer than, was determined for all samples that had a gradation such that 50% or more of the sample was retained on a No. 200 sieve. The results of this analysis are shown in Tables 4-11.

Analyzing the data collected downstream of Dike 114.0L shows that D_{65} varied from 0.14 mm to 0.60 mm and that D_{50} varied from 0.17 mm to 0.29 mm. This analysis produced an average D_{65} of 0.29 mm and an average D_{50} of 0.22 mm. Hydrometer tests were made on six of the samples. The results of these tests show that the % clay in the bed varied from 5.4% to 21.4%.

Eight bed samples were collected downstream of Dike 113.9L. The results of the sieve analysis show D_{65} to vary from 0.16 mm to 1.7 mm and D_{50} to vary from o.19 mm to 0.28 mm. The average values for D_{65} and D_{50} were respectively, 0.44 mm and 0.23mm. Two samples were checked for clay. One sample was 4.8% clay and the other 17.5% clay.

Analysis of the eight bed samples collected downstream of Dike 113.5L shows D_{65} to vary from 0.18 mm to 5.8 mm and D_{50} to vary from 0.13 mm to 0.88 mm. The average values for D_{65} and D_{50} were respectively, 1.56 mm and 0.80 mm. The clay content was determined for two of the eight samples and was found to be 10.7% and 21.2%.

Eight bed samples were collected downstream of Dike 103.3R. The results of the sieve analysis show that the bed material of all eight samples was finer than 0.074 mm. All of the material passed a No. 200 sieve. A hydrometer test was performed on all eight samples. The results

of this test show the clay content of the river bed downstream of this dike to vary from 12.2% to 29.8%.

Seven bed samples were collected downstream of Dike 103.2L. All the material in four of these samples passed a No. 200 sieve. Only one sample was such that less than 50% of the material passed a No. 200 sieve. This sample had a D_{65} of 0.27 mm and a D_{50} of 0.25 mm. All of these samples were tested for clay content which varied from 5.4% to 25%.

Analyzing the data obtained from the eight bed samples collected downstream of Dike 102.2L shows the bed material to be such that less than 50% of each sample passed a No. 200 sieve. The sieve analysis shows a variation in D_{65} from 0.31 mm to 13.0 mm and a variation in D_{50} from 0.18 mm to 5.2 mm. The average value for D_{65} was 3.4 mm and for D_{50} was 1.7 mm. The clay content was determined for two samples and found to be 4.8% and 24.5%.

Six bed samples were collected and anlyzed for Dike 100.1R. The results of the sieve analysis show that more than 65% of all the bed samples passed a No. 200 sieve. The clay content in these six samples varied from 12.2% to 30.4%.

Eight bed samples were collected downstream of Dike 98.9R. The material in four of these samples was such that more than 65% of it passed a No. 200 sieve. The clay content in these four samples varied from 4.5% to 28.4%. The other four samples show a variation in D_{65} from 0.50 mm to 8.5 mm and a variation in D_{50} from 0.41 mm to 2.7 mm. The average value for D_{65} was 2.8 mm and the average for D_{50} was 1.1 mm.

Hydrometer tests were performed on five of the eight samples that were collected. The results of this test show the clay content to vary from 4.5% to 28.4%.

Analysis of the bed material collected during this study tends to show that those samples collected downstream of notched dikes contain a higher percentage of sand than those collected downstream of conventional design dikes. This is believed to occur because of flow through the notch. The samples collected downstream of Dike 100.1R (notched with trail) contain a smaller percentage of sand than samples collected in like manner at notched dikes.

Velocity Data

Velocity measurements were taken at 0.6 of the depth of flow below the water surface at two or three points on each of the ranges below the dikes. The magnitude, direction and location of all point velocity observations are shown in Figures 119-148. The velocities were measured from an unanchored boat. Therefore, the direction and velocity of the wind had an effect on the low velocity (less than 1 fps) measurements because the current meter and direction apparatus were influenced by the boat movement. The boat was held in position by regulating the motor speed to match water and wind velocity. With the motor at idle speed the boat would move against water with a velocity less than one foot per second. Therefore, those point velocities and their direction that are less than one foot per second are questionable.

Due to the limited scope of this study, insufficient data prevented construction of mean velocity nets (lines of equal velocity) around the study dikes. However, flow pattern trends can be determined from the

data shown on Figures 119-148. Observation of these data will reveal that the trend around a modified dike is different from that downstream of an unmodified dike.

Bed Configuration Data

In order to examine the quantity of aggradation (deposition) and degradation (scouring) taking place below each of the eight study dikes, a computer program was written to calculate the amount of bed area and/or water area for each river bed profile. Incremental and Accumulated Bed and Water Areas were computed for each range or profile downstream of each of the study dikes and are shown in Tables 12-166.

The net change of accretion occurring at each dike was computed as follows: Refer to Figure 223 and Tables 50-69 for Dike 113.5L as an example. A top datum of 380 ft. MSL was taken as the maximum elevation for all ranges downstream of Dike 113.5L. A bottom datum of 300 ft. MSL was selected as the minimum elevation for each of these ranges. Using the trapezoidal rule of integration (Hornbeck 1975), incremental bed areas for each 50 feet of lateral stationing were computed between the river bed profile and the bottom datum. Likewise, incremental water areas were computed between the river bed profile and the top datum. These incremental areas were also accumulated up to the river end of the dike. Using the average end area method (Linsley, et al. 1982), total bed and water volumes downstream of each dike between ranges 1+00 and 9+00 were computed. The net bed and water areas and volumes below the elevation of the river end of each dike (as shown in Figures 7-14) were also computed and are shown in Tables 167-182 of the Appendix.

As can be seen from the data in Tables 167-182, there may be significant daily changes in water area due to the dynamic effect of the Mississippi River causing daily deposition and/or scouring of the bed material. The maximum volume change was ± 3 ac-ft/day over the 140-day study period. However, long-term trends towards the gain or loss of water surface area downstream of a dike cannot be detected from this 140-day study. This limited amount of data suggests a fluctuation about some average or mean value. It is believed that most of the changes can be accounted for locally or within the same dike field. In other words, much of the scouring at ranges 1+00 and 3+00 can be accounted for as deposition at ranges 5+00, 7+00 and 9+00, etc. For instance, taking the net change over the 140-day study period for Dike 103.3R shows scour at range 1+00 or 825 sq. ft., scour at range 3+00 of 675 sq. ft., fill at range 5+00 of 337 sq. ft., fill at range 7+00 of 1275 sq. ft. and fill of 1650 sq. ft. at range 9+00. This shows a net accretion of 1762 sq. ft. or a change of 8.52 percent.

Photographs and Other Data

A close examination of the lateral bed profiles, contour maps and photographs contained in the Appendix will reveal that there are different accretion patterns downstream of dikes that are subjected to different flow conditions. Examination of the bed profiles, photographs and contour maps will show a similarity in scour pattern immediately downstream of all dikes. However, analysis of the profile and contour plots will show definitely that a notch produces its own scour hole immediately downstream

of the notch. It appears that the size and shape of the scour hole might be related to the size and shape of the notch. This should be considered in any subsequent follow-up analysis or study.

V. BIOLOGICAL STUDY

A. GENERAL INTRODUCTION

Information on the aquatic communities associated with dikes in either the Missouri or Mississippi rivers has not been available until recently. Several studies of conventional and modified dikes (notched, rootless and lower elevation) have been completed on the Missouri River, and preliminary results are available from ongoing dike studies on the Mississippi River. Little is known of the biological communities associated with dikes in the Middle Mississippi River (that section of the Mississippi River extending from the mouth of the Missouri River to the mouth of the Ohio River) and no information is available on the effects of modified dikes.

The purpose of the biological portion of this study was to characterize the aquatic communities associated with three unnotched dikes and five notched dikes in the Middle Mississippi River. A notch is a gap or opening in the crest of a dike. The rationale for altering conventional dike design is to attempt to reduce land accretion and to provide a diversity of aquatic habitats downstream of channel regulating structures. Species composition and abundance of fish and macroinvertebrates at the eight dikes are compared and differences are reported among the dikes and between unnotched and notched structures. Recommendations are made for the management of fish and aquatic macroinvertebrates in the Middle Mississippi River based on the findings of this study and information available in the literature.

B. LITERATURE REVIEW

Information on the effects of channel regulating structures on fish and wildlife and their habitat was obtained from published and unpublished sources. A summary of each biological study involving regulating structures in the Missouri and Mississippi rivers is presented below. Missouri River studies were included in the literature review because 1) the Missouri River is biologically similar to the Mississippi River and 2) regulating structures in the Missouri River have been modified in an attempt to improve aquatic habitat.

Missouri River

Gould and Schmulbach (1973) and later Schmulbach et al. (1975) reported the results of a study on the distribution and relative abundance of fishes in unchannelized and channelized portions of the Missouri River from Gavins Point Dam to Rulo, Nebraska. Four types of habitat were sampled in the channelized river (Sioux City, Iowa to Rulo, Nebraska): main channel,wing dikes (a structure that extends from the shoreline at an oblique angle to the current), L-head dikes (a wing dike with a trail extending downstream from the tip of the dike parallel to the current), and the confluence of tributary streams. They concluded that the species composition around L-head dikes was diverse; shortnose gar, gizzard shad, goldeye, carp, and river carpsuckers were the most abundant species found near these dikes. Gizzard shad, goldeye,and river carpsuckers were the most abundant species collected near wing dikes, with shovelnose sturgeons and smallmouth buffalo also occurring in the strong eddy currents below the wing dikes.

As part of another study on unchannelized and channelized portions of the Missouri River in South Dakota, Nebraska and Iowa, Kallemeyn and Novotny (1977) evaluated the ecological effects of notching dikes and revetments (a dike that is parallel to the original river bank; used to form the concave bank alignment in open water). Data were collected on unnotched and notched wing dikes, notched (in wing portion) L-head dikes, and notched revetments. They found that three species, carp, river carp-suckers, and channel catfish, comprised approximately 70% of the fish collected from these habitats. Channel catfish were found in areas with substantial velocity while other species occurred primarily in slower water. The largest catches of fish in the channelized river (below Sioux City, Iowa) came from habitats created by the modified channel regulating structures. Fish catches at these structures were similar to those from backwaters and chutes in the unchannelized river (below Fort Randall and Gavins Point dams). They recommended the following:

"Structures to reduce bank erosion should be designed to maintain habitat diversity and include the provision of some flow to backwater areas and chutes; sediment should not be allowed to accumulate in these critical habitats. Construction materials such as large rocks should be used where structures are required to provide substrates for fish food organisms.

The Corps of Engineers' notching program should be continued in the channelized river to create additional shallow water habitat. Further study is needed to determine the best means of creating and maintaining these habitats."

Hesse et al. (memo dated 9 March 1981) from Larry W. Hesse et al., Fisheries Research, Missouri River Branch, Nebraska Game and Parks Commission) have investigated the winter usage of dikes by fish in the Missouri River, Nebraska. Carp, freshwater drum, river carpsuckers, goldeye, and channel catfish were collected in sufficient numbers to make population estimates. A winter estimate of 815 fish per dike was made for carp, freshwater drum, river carpsuckers, and goldeye combined. Channel catfish were found wintering in the scour hole created by the dike. An estimated 1,914 channel catfish were associated with each dike in the study area. Additional fieldwork is planned.

Jennings (1979) investigated eight notched dikes on the Missouri River, central Missouri, to evaluate the suitability of the associated habitat for fishes. He studied two wing dikes, four L-head dikes, and two parallel revetments. Both wing dikes were located above the openings of chutes. The L-head structures were notched as follows: one in the wing portion, two in the trail portion, and one in both the wing and trail portions of the dike. Parallel revetments were connected to shore at each end with wing dikes. One structure was notched in the revetment and the other in the downstream wing portion.

The enclosed, parallel revetments provided substantially better aquatic habitat for fish than did any of the L-head dikes studied, in terms of catch per unit effort, species diversity, and length-frequency distribution of fish. These enclosed pools provided nursery and rearing areas for several fish species. The abundance of young fishes in these areas was thought to be related to the abundance of zooplankton. Standing crop and number of zooplankton taxa were higher in an enclosed pool than

in the river channel or at an L-head dike studied. The benthic invertebrate community in the enclosed pool was also more diverse and different in structure than that at the L-head dikes.

A chute below a notched wing dike supported greater numbers and biomass of benthic invertebrates than did an enclosed, parallel revetment or two L-head dikes studied, although their respective faunas were distinctly different. The chute also supported slightly more taxa of benthic organisms than any other area. Jennings (1979) concluded that the chutes below the notched wing dikes provided better habitat for fishes than the L-head dikes. These chutes contained an abundance of channel catfish and freshwater drum, which he related to the high densities of benthic organisms. These areas were thought to be important nursery and rearing areas for some fish species.

L-head dikes were considered to provide marginal habitat for zooplankton, benthos, and fish. Zooplankton were less diverse and lower in abundance in an L-head dike area than in an enclosed pool. Fewer benthic invertebrate taxa occurred at L-head dikes than at either the chutes or enclosed pools. Benthos were also less abundant at the L-head dikes than in a chute. Jennings (1979) felt that L-head dikes offered little potential as fish nursery areas. He noted, however, that flathead catfish were associated with submersed trail dikes and overall, L-head dikes provide more suitable fish habitat than the border of the main channel.

Jennings (1979) concluded that notched dikes alone cannot reclaim habitat which has been lost due to channelization, but should be included with other habitat restoration methods to improve and provide additional habitat in the Missouri River.

Robinson (1973, 1977, and 1980) has conducted several studies involving dikes on the Missouri River in central Missouri. During 1970 to 1972, Robinson (1973) evaluated selected channel regulating structures in the Missouri River as habitat for fish. Three wing dikes and one L-head dike were studied. All structures were unnotched and consisted of wooden pilings and large angular rock.

No significant differences in fish species composition or length-frequency distribution were found among the study areas. Length-frequency data did seem to indicate that the habitat behind the dikes served as rearing areas for many species. Analysis of benthic invertebrate data also revealed no differences among the study areas. However, many of the invertebrate taxa collected in the study area occurred in the stomachs of carp and river carpsuckers. Robinson (1973) concluded that fishes were utilizing the habitat behind these dikes and might be using these areas for feeding, rearing, and spawning.

Robinson (1977) reported on the fish usage of habitats created by rock dikes, and the movement of flathead catfish in the Missouri River. He found that skipjack herring, blue suckers, flathead catfish, and white bass were most abundant in swift water near dikes. Shovelnose sturgeon, paddlefish, longnose gar, shortnose gar, channel catfish, black bullheads, carp, bigmouth buffalo, river carpsuckers, bluegill, white crappie, and freshwater drum were taken most frequently in slow moving water along mud banks. Gizzard shad, goldeye, blue catfish, and sauger were taken in nearly equal numbers from both of the above habitats.

Flathead catfish were sedentary, and were usually found near some type of cover. Eighty percent of the recaptured fish were taken less

than 1 mile from their original release site. They were found near submersed trees, floating debris, old pilings, brush piles, and large angular rock.

Robinson (1980) studied modified dikes (notched, rootless, and lower elevation) in the Missouri River from 1976 to 1979 to determine whether they created conditions favorable for fish. Eight rock dikes (one conventional and seven modified) were selected for study. Fish species composition, relative abundance, and diversity measures were similar at all dikes. However, the greatest number of species, number of fish, and pounds of fish were collected at a conventional dike (high, unnotched structure) where there was slack water. This suggested a need to the author for permanent habitat of this type. Robinson concluded that habitat conditions were favorable for fishes at all dikes, and that variety in dike construction would provide more habitat diversity than only one type of dike.

Burke and Robinson (1979) provided an excellent overview of the history and effects of conventional and modified channel regulating structures in the Missouri River. They concluded that:

"Great care and expertise will be needed by both the biologist and engineer to create a diverse aquatic habitat at various water levels without causing further land accretion, permanent water surface losses, bank erosion, or impairing the usefulness of the navigation channel."

Mississippi River

Fernholz (1980) reported the results of a project designed to document the use of wing dikes, riprap, and sand habitats by fish in Pool 8 of the Upper Mississippi River. Large walleye, sauger, and smallmouth

bass preferred the wing dikes to riprap or sand. Rock riprap supported the greatest number of fish species and served as nursery and rearing areas for walleye, sauger, smallmouth bass, bluegill, and black crappie. The sand habitat was used primarily at night as migration routes and feeding areas for various species. Gizzard shad was the most abundant species in the sand habitat.

The Iowa Conservation Commission is currently conducting a study of wing dikes and closing structures along the Iowa border of the Upper Mississippi River in Pools 9 through 19. They plan to eventually make recommendations for the modification and construction of river regulating structures that would meet the hydraulic needs for the dike, but also be beneficial to the river's fisheries. Boland (1980) and Pitlo (1980) reported on the first segment of the study, which was an inventory, description, and classification of the physical properties of the structures. Pitlo (1980) also reported preliminary results of fish collecting at selected structures. More fish were captured during nighttime sampling than daytime and more fish were captured downstream of the structures than upstream.

Hall (1980) and Pierce (1980) reported on the prenotching phase of a project to determine the effects of wing dike notching on associated fish and aquatic macroinvertebrate communities in Pool 13 of the Upper Mississippi River. The results of the post-notching study will be available in 1982 (Corley, in preparation).

Hall (1980) compared species composition, density, and biomass of the aquatic macroinvertebrates at six wing dikes and an adjacent side channel. In general, he found greater densities, biomass, and number

of benthic invertebrate taxa in silt-clay substrates than in sand substrates. Although gravel substrate was rare, the highest benthic invertebrate density, biomass, and number of taxa occurred in gravel. Hall concluded that if notching increases the percentage of sand in the substrate, it would adversely affect bottom-dwelling macroinvertebrates in the study area. He also found that basket samplers (metal baskets filled with concrete spheres) placed on the dikes collected 26.5 times more macroinvertebrates and 14.3 times more biomass than Ponar grab (dredge) samples of the bottom sediments around the wing dikes. Hall implies the importance of a stable substrate in the river by describing wing dikes as "islands of rock in a sea of sand."

Pierce (1980) determined the species composition and relative abundance of fish at the same dikes and side channel studied by Hall (1980). Thirty-eight of 52 fish species collected in the study area were caught on or near wing dikes. Electrofishing catch rates of fish species and number of fish caught were highest in the side channel, followed by main channel border shorelines, and emergent wing dikes. The composition of electrofishing catches in these three areas was generally similar. The wing dikes with more riprap, stumps, and logs along their shorelines, most often demonstrated the greatest species diversity and highest catch rates of fish. Pierce (1980) concluded that wing dikes add to the diversity of cover types found in the main channel border and may provide important cover or shelter from current if substantial accretion of sediment does not occur between dikes.

Two other studies on the Mississippi River, involving investigations of dikes, are in progress. Environmental Science and Engineering, Inc.,

(a consulting firm) is classifying, inventorying, and describing the biotic conditions associated with the majority of aquatic habitat in the Mississippi River from Lock and Dam No. 22 at Saverton, Missouri, to the mouth of the Ohio River at Cairo, Illinois (Keith Govro, personal communication on 13 April 1981, Environmental Science and Engineering, Inc., St. Louis, Missouri). Field studies were completed in 1981. The Waterways Experiment Station, United States Army Corps of Engineers, is conducting an investigation designed to develop environmental quality guidelines for planning, designing, and constructing and/or modifying structures used in waterways projects (United States Army Corps of Engineers 1981). Fieldwork was completed on the Mississippi River near Greenville, Mississippi in 1980.

C. MATERIALS AND METHODS

Biological and water quality characteristics at each dike were determined during four sampling periods in 1981: 14 April to 30 May, 18 June to 29 July, 17 August to 3 September, and 5 October to 16 October. Fish and macroinvertebrate communities were sampled; dissolved oxygen, water temperature, and turbidity were measured; and observations of mammals, birds, reptiles, and amphibians in the vicinity of each dike were recorded.

Fish

A variety of collecting methods were used to capture a representative sample of the fish community associated with each dike. Fish were collected with electrofishing gear, hoop nets, gill nets, and trammel nets downstream of each dike. Field notes describing the approximate sampling location for each type of gear are on file at the Missouri Department of Conservation, Fish and Wildlife Research Center, 1110 College Avenue, Columbia, Missouri 65201.

Electrofishing gear consisted of a boat-mounted boom shocker with continuous direct current (D.C.). The power source was an Onan single phase, 60 hertz (Hz), alternating current (A.C.) alternator with a capacity of 3,000 watts at either 120 or 240 volts. Tne current was rectified and adjusted by a control box developed at the Electronics Instruments Laboratory at the University of Missouri-Columbia. Each dike and approximately 300 feet of shoreline immediately downstream were electrofished with 130 to 160 volts, 6 to 10 amps. Fish communities at each dike were sampled four times during the study (once

during each sampling period). Catch rate was expressed as number of fish captured per hour.

Two sizes of hoop nets were used: 1 in. square mesh with 2-1/2 ft. diameter hoops and 2 in. square mesh with 3-1/2 ft. diameter hoops. All nets were 15 ft. long. Each hoop net had seven hoops with throats on the second and fourth hoops. Hoop nets were set (with the opening downward of the flow) with a 20 to 30 ft. cod rope and rock anchor, where the current was sufficient to keep the net open. A rope yoke and anchor were added to the mouth of the hoop net to stretch it open while sampling in slack water. Two hoop nets of each size were fished per dike for 2 days each sampling period. Hoop nets were normally set in water less than 15 ft. deep, usually parallel to the dike, shoreline, or in the current downstream of a notch. Hoop nets were run each day, catch rate was expressed as number of fish captured per net day (24 hours).

One experimental gill net and one trammel net were fished for 1 day per dike during each sampling period. Experimental gill nets were 125 ft. x 6 ft. with five 25-foot panels of the following square mesh sizes: 3/4, 1, 1-1/4, 1-1/2, and 2 inches. The smaller mesh sizes of the experimental gill nets were set in shallower water. Trammel nets were 195 ft. x 6 ft. with 2 in. square mesh on the inner panel and 14 in. square mesh on the outside panels. These nets were usually set in slack water less than 20 ft. deep with one end of a net attached to either the dike or shore. Catch rate was expressed as number of fish captured per net day (24 hours).

Length (mm) and weight (g) information was recorded for all fish except minnows. Fork length was measured on sturgeons and paddlefish. Total length was measured on all other species. Fish were identified according to Pflieger (1975). Common and scientific names of fishes

used in this report are those endorsed by the American Fisheries Society (Robins 1980) and are given in Table 134 of the Appendix.

Aquatic Macroinvertebrates

Aquatic macroinvertebrates were sampled with artificial substrate samplers and a BM 54 Sediment Sampler. An artificial substrate sampler consisted of a round-wire (barbecue) basket 6-1/2 in. diameter and 10 in. long filled with 2 to 4 inch diameter limestone rocks, a 4 in. x 4 in. x 11 in. modified multiple-plate sampler (Hester and Dendy 1962), and a 16 in. x 21 in., 12 in. deep bottom screen (Duchrow 1976; Fig. 225). The BM 54 Sediment Sampler grabs a portion of the bottom sediments measuring approximately 3 by 3 inches.

Three artificial substrate samplers were placed on the bottom downstream from each dike during 6-7 May. The contents of each sampler were removed on 18-19 June, 18-20 August, and 6-9 October. Invertebrates were allowed to colonize samplers for about 6 weeks prior to removal. Samplers were replaced if they could not be recovered. Field notes describing the approximate location of each sampler are on file at the Fish and Wildlife Research Center.

Each sampler was disassembled and thoroughly washed in a benthos pan to remove the invertebrates. A benthos pan consisted of a plastic tub with a bottom constructed of 30 mesh to the inch wire screen. Organisms and detritus were preserved in 10% formalin.

Grab (dredge) samples were collected at two sites (stations 4 and 7, Fig. 226) below each dike during 14-18 September and 13-17 October by personnel of the Institute of River Studies, University of Missouri-Rolla.

Grab (dredge) samples were preserved in 10% formalin, brought to the laboratory, and washed over a U.S. No. 35 Standard Sieve.

Invertebrates were handpicked from the samples in the laboratory. Most of the organisms were removed from debris by the sugar flotation method (Anderson 1959). The entire sample from an artificial substrate sampler was not picked if it contained an unusually large amount of debris. Instead, the contents were subsampled and invertebrate counts were extrapolated to estimate the total sample.

Invertebrates were identified and counted using compound and binocular dissecting microscopes and the following references for identification: Bednarik and McCafferty (1979), Burks (1953), Grabau (1955), Merritt and Cummins (1978), Schuster and Etnier (1978), Ward and Whipple (1959), and Wiggins (1977).

Water Quality

Water quality characteristics were measured at mid-depth at seven stations on 29 May, 29 July, 3 September and 8 October at each dike (Fig. 226). Dissolved oxygen concentration and water temperature were measured with a YSI (Yellow Springs Instrument Company) Model 54 Oxygen Meter. The oxygen-temperature meter was calibrated each day with a mercury thermometer for water temperature and with the azide modification of the Winkler titration (American Public Health Association 1971) for dissolved oxygen. Turbidity samples were collected with a Kemmerer water sampler and measured with a Hach Model 1860 Laboratory Turbidimeter. Depth was determined with a Lowrance Model LRG 610A Flasher-Graph (depth finder).

Wildlife Observations

Casual observations of mammals, birds, reptiles, and amphibians were made during the study. Use of aquatic and adjacent riparian habitat at each dike was of particular importance.

Margalef Index

Species diversity index values were calculated for fish and macroinvertebrate communities. An equation derived by Margalef (1957), and discussed by Wilhm (1967) and the United States Environmental Protection Agency (1973), was used:

$$\underline{d} = \frac{s-1}{\log_e N}$$

where s equals the number of taxa and N equals the total number of organisms in the sample. The Margalef index value summarizes data on the total number of organisms and total number of taxa in a sample; however, it is primarily a measure of species richness (number of species). Higher index values indicate greater species diversity.

The Shannon-Weaver diversity index ($\bar{d}$) has been applied to biological data collected in previous studies on the Missouri and Mississippi rivers. In order to facilitate comparison with other studies, corresponding Shannon-Weaver diversity index values are included in all tables listing the Margalef index. The Shannon-Weaver index, also discussed by the United States Environmental Protection Agency (1973), is as follows:

$$\bar{d} = \sum_{i=i}^{s} \left[(n_i/n) \log_2 (n_i/n) \right]$$

where s equals the number of taxa in the sample, n_i equals the number of organisms in the i^{th} taxon, and n equals the total number of organisms in the sample. The Shannon-Weaver index is affected by both richness (number) of species and by distribution of individuals among the species.

D. DISCUSSION OF RESULTS

Water levels in the study area remained high from late spring through much of the summer during 1981 (Fig. 227). High water conditions existed during much of the fieldwork conducted in May, June, and July. The river receded to more normal seasonal levels, from late August to October, for the remainder of the fieldwork. All references to river stage refer to the United States Geological Survey gage at Chester, Illinois. The datum (0.0 ft) of the Chester, Illinois gage is 341.05 ft above mean sea level.

Fish

A total of 4,512 fish, representing 45 species, were collected during this study at the eight dikes on the Middle Mississippi River (Tables 184 and 185). Forty-three species were captured by electrofishing and netting (hoop, gill, and trammel nets). Single specimens of the tadpole madtom and stonecat were collected in invertebrate samplers. Two items of interest were noted in regard to the condition of fish collected: (1) five of the ten paddlefish had their rostrums (paddles) broken off; and (2) a number of shovelnose sturgeon and carp were deformed.

Species composition and relative abundance

Seven species comprised 85% of the fish collected: gizzard shad, 53%; carp, 10%; river carpsuckers, 8%; freshwater drum, 6%; shortnose gar, 3%; emerald shiners, 3%; and flathead catfish, 2% (Table 185). These species were collected at all eight study dikes. All other species each made up less than 2% of the catch. Gizzard shad was the only species

considered abundant (more than 10% of the catch). Twelve species were common (1 to 10% of the catch), thirteen species were uncommon (0.1 to 1% of the catch), and the nineteen species were rare (less than 0.1% of the catch; Table 185).

Dominance by a few species of fish is not uncommon in samples from big rivers. Ragland (1974) also found carp, gizzard shad, river carpsuckers, and freshwater drum to be the most abundant species in side channels and main channel border habitats in the same area on the Mississippi River. In the Missouri River in South Dakota, Nebraska, and Iowa, river carpsuckers, gizzard shad, and carp comprised 77% of the catch in one study (Gould and Schmulbach 1973) and carp, river carpsuckers, and channel catfish comprised 70% of the catch in another study (Kallemeyn and Novotny 1977).

No federally endangered fish species are currently found in the Middle Mississippi River (United States Department of the Interior, Fish and Wildlife Service 1976). Missouri and Illinois, however, have listed species that are considered threatened within their jurisdictional boundaries (Missouri Department of Conservation 1977; Illinois Department of Conservation 1978). No species on the Illinois list were captured. However, single specimens of the pallid sturgeon ("endangered") and Alabama shad ("rare") on the Missouri list were taken. The pallid sturgeon is rare throughout its range and is found principally in the Missouri and Middle and Lower Mississippi rivers (Carlson and Pflieger 1981). The Alabama shad is anadramous and has been found in the Mississippi Valley from Iowa southward and in the Gulf Coastal drainages (Pflieger 1971). Alabama shad are more common in the southern portion of their range.

Fish can be grouped into categories to provide a simpler view of habitat suitability near dikes of different design. Christenson and Smith (1965), Ellis (1978), and Pierce (1980) grouped fish species from the Upper Mississippi River into six categories: game fish, panfish, catfish, predatory rough fish, forage fish, and rough fish. Eleven groups of fish were selected for this analysis: sturgeons, paddlefish, herring, carp, buffalo, carpsuckers, catfish, white and yellow bass, sunfish, walleye and sauger, and freshwater drum. Important recreational, commercial, and prey species were selected, and grouped according to similar habitat requirements.

Distribution of the 11 groups of fish varied from dike to dike (Table 186). Samples of 100 fish or less of a particular species were not evenly distributed in the study area. Most sturgeons, for example, were found at dike 98.9R, whereas most paddlefish were found at dike 103.2L. Large samples of a particular species of fish were generally well distributed among the study dikes. One notable exception was the scarcity of freshwater drum at dike 102.2L (Table 186).

Percentage composition of the 11 fish groups was compared at the three unnotched and five notched study dikes. The relative abundance of herring, carp, carpsuckers, catfish, white and yellow bass, and sunfish was similar at the unnotched and notched dikes. Paddlefish and freshwater drum were more common near the unnotched dikes, while sturgeons, buffalo, and walleye and sauger were more abundant at the notched dikes (Table 187). However, none of the differences in relative abundance were significant (t-test with $P \leq 0.10$). The abundance of sunfish at the study dikes was probably influenced more by cover than the presence or absence

of a notch. In particular, crappie were most frequently found near the remains of old pile dikes.

Specific characteristics of the habitat associated with different dikes probably account for differences in relative abundance of the 11 groups of fish. Jennings (1979) found a significant difference in species composition of the fish communities associated with eight notched dikes in the Missouri River in central Missouri. Robinson (1977), Schmulbach et al. (1975), and Kallemeyn and Novotny (1977) reported habitat preferences for fish in the Missouri River in relation to water velocity. Bailey and Cross (1954) found pallid and shovelnose sturgeons in areas with swift current and a sand or gravel bottom. Paddlefish are more commonly found in pools or slow-flowing waters in rivers (Pflieger 1975; Smith 1979).

Species diversity

A total of 45 species of fish were collected during the study. Ragland (1974) collected 42 species of fish in a larger study area on the Middle Mississippi River. Pierce (1980) collected 52 species of fish in an area with six wing dikes and a side channel on the Mississippi River in Illinois. Robinson (1973, 1977, 1980) captured 36, 33, and 37 species, and Jennings (1979) collected 42 species of fish in separate studies of dikes on the Missouri River in central Missouri.

The number of species of fish and specimens captured varied among the eight study dikes (Table 188). The greatest number of species collected was 31 at dike 113.9L which is notched. The fewest number of species collected was 21 at dike 103.3R which is unnotched. The most (682) and

least (477) fish were taken at notched dikes, 100.1R and 102.2L, respectively.

Values of Margalef's d for fish communities in the Middle Mississippi River ranged from a low of 3.23 at dike 103.3R to a high of 4.76 at dike 113.9L (Table 188). Fish communities in big rivers tend to be quite diverse. Gould and Schmulbach (1973) and Kallemeyn and Novotny (1977) found this to be true around wing dikes in the Missouri River, as did Ragland (1974) and Pierce (1980) in the Mississippi River. Jennings (1979) reported values of Margalef's d ranging from 2.23 to 4.19 for fish communities associated with dikes in the Missouri River. Robinson (1980) reported Margalef's d values from 3.10 to 3.94 for fish communities at individual dikes during a 4-year study on the same section of the Missouri River.

Diversity of fish communities was compared at the unnotched and notched study dikes. A total of 33 species of fish were collected at unnotched dikes as compared to 42 species at notched dikes. Diversity of fish communities at notched dikes ($\underline{d}$ = 4.04) was slightly greater than at unnotched dikes ($\underline{d}$ = 3.75; Table 188); however, this difference was not significant (t-test, $P \leq 0.40$).

Catch per unit of effort

Electrofishing was a more efficient method than netting to sample fish communities associated with dikes in the study reach of the Middle Mississippi River. An average of 153 fish per hour were taken with electrofishing gear (Table 189). All netting took an average of only 5.3 fish per net day (24 hours). Trammel nets (21 fish per net day) were

the most effective net type. Gill nets (17 fish per net day) were nearly as effective and hoop nets (2.1 fish per net day) were least effective (Table 189). Catch rates in this study were similar to those of Ragland (1974),who also sampled the Middle Mississippi River.

Seasonal differences in numbers of fish captured near dikes were probably related to river stage and possibly related to spawning activity in the Middle Mississippi River during 1981. Sampling was most effective in April and May (first sampling period) at a river stage of 12.4 to 21.5 feet. Electrofishing captured 314 fish per hour in the spring, and all nets combined caught 6.5 fish per net day during the same period (Table 190). The Mississippi River reached flood stage (27 feet) in June and July (second sampling period) and was between 17.5 and 27.1 feet when fish communities were sampled. Neither electrofishing nor netting (except hoop netting) were very successful at that time (Table 190). Overall catch per unit of effort was average in August (third sampling period) and October (fourth sampling period) at a river stage of 11.5 to 17.5 feet and 7.8 to 9.2 feet, respectively.

The general success of each type of sampling gear was related to river stage. Electrofishing was most effective when the river stage was around 14 feet (Fig. 228). Catch decreased at lower river stages because some of the habitat was exposed. At higher river stages, more habitat was inaccessible to electrofishing equipment because of terrestrial plant growth near normal bank levels. Pierce (1980) and Gutreuter (1980) also reported low catch rates while electrofishing at a relatively high river stage in the Upper Mississippi River. In this study, hoop nets were most effective at river stages between 19 and 26 feet, and entanglement nets

(gill and trammel) were most effective at a river stage less than 13 feet (Fig. 228). Hoop nets caught more fish at higher river stages in fairly strong current, whereas gill and trammel nets caught more fish at lower river stages in slack water. Gutreuter (1980) also had good success with hoop nets at high river stages in the Mississippi River in Pools 20, 21 and 22. Pierce (1980), on the other hand, found that the catch rate for hoop nets was negatively correlated with mean monthly discharge in the Mississippi River in Pool 13.

The number of fish captured with a given amount of effort by a particular method has frequently been used to estimate relative abundance. The standing crop of fish in the study reach of the Middle Mississippi River probably exceeds that of the Missouri River, based on a comparison of catch rates. Catch rates from this study, and those of Pierce (1980), Ellis (1978), and Ragland (1974) from the Mississippi River, in general exceeded those of Jennings (1979), Schmulbach et al. (1975), and Robinson (1973) who sampled the Missouri River with similar gear. Sampling bias of a particular gear type was minimized by sampling with three types of nets and by electrofishing. The result should be a fairly representative sample of large species in which total numbers of fish can be compared on a dike to dike basis.

Catch of fish per unit of effort was compared at the unnotched and notched study dikes. A greater number of fish were taken per hour by electrofishing at notched compared to unnotched dikes (157 versus 145 fish per hour; Table 189). However, netting was slightly more effective at unnotched dikes (5.4 versus 5.2 fish per net day). An analysis of variance showed no significant differences between catch rate by electrofishing or

netting at unnotched and notched dikes. Catch rates with electrofishing gear showed significant ($P \leq 0.01$) seasonal differences which were probably related to river stage. Therefore, abundance of all species of fish combined at a study dike was not found to be influenced by the presence or absence of a notch in the dike. In related studies, however, Kallemeyn and Novotny (1977) recorded the largest catches of fish near notched revetments and dikes in a channelized section of the Missouri River below Sioux City, Iowa.

Length-frequency analysis

Eleven species of fish were selected for analysis because of their abundance and value to commercial and recreational fisheries (Tables 191 to 201). Gizzard shad, bigmouth buffalo, channel catfish, blue catfish, and black crappie were all significantly larger at unnotched dikes than at notched dikes (t-test with $P \leq 0.10$; Table 202). There was no significant difference in size between carp, river carpsuckers, flathead catfish, white bass, white crappie, or freshwater drum collected at unnotched and notched dikes. In no instance were any of the eleven species significantly larger at notched dikes in this study. Jennings (1979) found that the habitats resulting from notched dikes in the Missouri River, central Missouri, were suitable for various sizes of gizzard shad, carp, river carpsuckers, channel catfish, flathead catfish, white crappie, and freshwater drum.

Aquatic Macroinvertebrates

A total of 44,358 macroinvertebrates, representing 55 taxa, were collected with artificial substrate samplers and a grab (dredge) sampler during the study (Table 203). Just over half of the artificial substrate samplers (37 out of 72) were recovered. At least one sampler was recovered from every dike in each retrieval period (second, third, and fourth sampling periods). Grab (dredge) samples were collected in the third and fourth sampling periods, and supplemented data obtained from the artificial substrate samplers.

A distinction in benthic invertebrate communities has been made based on substrate colonization. Herpobenthos inhabit bottom sediments, whereas haptobenthos are associated with submersed substrates such as snags, roots, brush piles, or large rocks (Neuswanger 1980). Both of these overlapping communities were sampled with the artificial substrate samplers. Haptobenthos colonized the multi-plate portion of our samplers and exposed wire baskets filled with rocks. Herpobenthos colonized the silt-covered wire baskets and bottom screens.

Species composition and relative abundance

Three groups of organisms comprised 85% of the invertebrates collected: aquatic earthworms (oligochaetes), 59%; mayflies (ephemeropterans), 14%; and flies (dipterans), 12% (Table 204). Representatives of each of these three groups were found at all eight dikes. Other common invertebrates included caddisflies (trichopterans) and damselflies and dragonflies (odonates). The "Other" category in Table 204 is comprised of a wide variety

of invertebrates including beetles, alderflies, aquatic sow bugs, scuds, crayfishes, freshwater prawns, leeches, horsehair worms, flatworms, roundworms, snails, limpets, fingernail clams, and freshwater mussels.

Dominance by a few groups of invertebrates is common in samples from big rivers. Munger et al. (1974) found species composition to vary dramatically among study sites on the Missouri River. Neuswanger (1980) found significant differences in abundance for a number of taxa from site to site in side channels in Pools 20, 21, and 22 of the Upper Mississippi River. Generally, insects outnumbered oligochaetes in collections from the Missouri River (Robinson 1973, 1980; Jennings 1979; Kallemeyn and Novotny 1977). Dominant groups varied in collections from these studies. In the Upper Mississippi River, oligochaetes were often more abundant than insects (Hall 1980; Neuswanger 1980).

Distribution of the more abundant groups of invertebrates varied from dike to dike in the study reach of the Middle Mississippi River (Table 204). Mayflies and flies were plentiful at dike 98.9R, but aquatic earthworms were less common than at the other dikes. Caddisflies were abundant at dike 102.2L, but scarce at dikes 103.2L and 103.3R. Aquatic earthworms were extremely abundant at dikes 103.2L and 103.3R (Table 204).

Differences in percentage composition of macroinvertebrate communities were dramatic when comparing unnotched and notched dikes on an annual basis. Notched dikes were characterized by relatively high numbers of caddisflies (t-test, significant at $P \leq 0.10$) and flies, with fewer aquatic earthworms. The reverse is true at unnotched dikes with aquatic earthworms being significantly more abundant (t-test, $P \leq 0.10$; Table 204) than caddisflies and flies. These differences could be related to changes in water velocity and

substrate that result from notching dikes. Robinson (1973) did not find any significant differences in species composition of invertebrate communities among study areas on the Missouri River.

The percentage composition of marcoinvertebrate communities varied seasonally at the study dikes in the Middle Mississippi River. Aquatic earthworm populations were reduced during the high water in June, July, and August. Their abundance was high in the spring and fall and low in the summer (Table 205). Nearly all insects (Class Insecta) were relatively more abundant in the summer than in the spring or fall (Table 205). Neuswanger (1980) found that abundance of oligochaetes was negatively related to water velocity in the Upper Mississippi River, and he speculated that this was due to a change in substrate from silt to sand as water velocity increased. The variation in abundance of benthic invertebrate groups may also have been related to population cycles, i.e., emergence or life stages too small to be retained by sampling methods.

Species diversity

A total of 55 taxa of invertebrates were collected during this study. Ragland (1974) collected 55 and 73 taxa with artificial substrate samplers in side channels and main channel border areas, respectively, in the Middle Mississippi River. Hall (1980) collected 35 taxa with artificial substrate samplers at six dikes in Pool 13 of the Upper Mississippi River.

The number of taxa of invertebrates and total number of organisms varied among the eight study dikes (Table 206). The largest number of taxa collected was 34 at dike 102.2L which is notched. The smallest number of taxa collected was 18 at dike 103.2L which is unnotched.

Values of Margalef's $\underline{d}$ ranged from a low of 1.58 (average value per sampler) at dike 103.2L to a high of 2.74 (average value per sampler) at

dike 98.9R in the Middle Mississippi River (Table 206). This index can vary from 0 to 10 for invertebrate communities in Missouri streams (Duchrow et al. 1980). Ragland (1974) did not find any appreciable difference in diversity of invertebrate communities at sites in main channel border areas and side channels of the Middle Mississippi River. Jennings (1979) and Robinson (1980), in separate studies, reported $\underline{d}$ values of 2.17 to 3.71 and 2.79 to 4.02, respectively, for invertebrate communities at four dikes in the Missouri River.

Diversity of the invertebrate communities was compared at unnotched and notched dikes. A total of 30 taxa of invertebrates were collected at unnotched dikes as compared to 51 taxa at notched dikes. Diversity of invertebrate communities was significantly greater (t-test, $P \leq 0.10$) at notched dikes ($\underline{d} = 2.19$) than at unnotched dikes ($\underline{d} = 1.74$) in the study reach of the Middle Mississippi River (Table 206).

Catch per unit of effort

A total of 44,216 invertebrates were collected with artificial substrate samplers at the eight dikes during the study. An average of 1,196 invertebrates colonized each sampler in each season (Table 207). A total of 142 invertebrates were collected with a grab (dredge) sampler, for an average of 4.4 invertebrates per grab (Table 208). Jennings (1979) found about the same average number of invertebrates per artificial substrate sampler, but reported more dramatic differences in abundance from dike to dike in the Missouri River.

Numbers of invertebrates collected per sampler were compared at unnotched and notched dikes. Invertebrates were 70% more abundant at

notched dikes (significant at $P \leq 0.10$, t-test) than at unnotched dikes (Table 207). An average of 1,346 and 791 invertebrates per sampler were collected at each notched and unnotched dike, respectively.

Seasonal differences were also found in the number of invertebrates collected from the study reach of the Middle Mississippi River. The greatest number of invertebrates (1,802 per sampler) were taken in the spring (Table 209). Abundance of organisms was lowest in the summer (790 per sampler), and slightly higher in the fall (921 per sampler). The decrease in abundance might have resulted from high water conditions in June, July, and August, and insect emergence.

Substrate can be a critical factor in determining invertebrate abundance. If a notch in a dike changes the water velocity and substrate behind the dike, invertebrate communities can be altered. It has been well documented that if the substrate changes from silt to sand, invertebrate abundance decreases. On the other hand, Neuswanger (1980) found haptobenthos to be positively associated with water velocity in the Upper Mississippi River. Therefore, the diversity of habitats created behind a notched dike may be beneficial.

Water Quality

Three measures of water quality were monitored during the study: water temperature, dissolved oxygen, and turbidity. Each variable was measured at seven stations at each dike during the four sampling periods. Water temperature, dissolved oxygen, and turbidity varied seasonally. However, no significant differences were recorded from station to station or dike to dike. Results are summarized in Table 210. Homogeneity of water quality variables was expected because of the high water during the study.

Water temperature varied from 17.7 to 26.0°C between May 29 and October 8, 1981 in the study reach of the Middle Mississippi River (Table 210). Dissolved oxygen varied from 5.7 to 9.7 mg/l at the same time. Oxygen levels fluctuated in relation to water temperature. As temperature increased, the level of dissolved oxygen decreased (Table 210). Turbidity varied from 46 to 82 JTUs, with levels remaining similar during the first, second, and third sampling periods (an average of 75, 78, and 69 JTUs, respectively). Turbidity readings were lowest during the fourth sampling period (an average of 52 JTUs) as the river dropped to its lowest level during the study.

Wildlife Observations

Casual wildlife observations were made during fieldwork. A list of animals and animal signs observed between April 14 and October 16, 1981 in the vicinity of the eight study dikes on the Middle Mississippi River is presented in Table 211. No attempt was made to quantify the sightings.

VI. SUMMARY AND RECOMMENDATIONS

The data collected for the engineering and biological phases of this study were obtained over a time period of 140 days and 186 days, respectively. The scope of study limited data collection to four sampling periods during the study at eight dikes pre-selected from the study reach of the Middle Mississippi River. Therefore, any results or conclusions drawn from the limited amount of data collected must be qualified accordingly.

The bed samples collected during the engineering study indicate that the bed material downstream of notched structures will contain a higher percentage of sand than the material downstream of an unmodified structure. The addition of a trail to a notched structure, according to the data collected in this study, will reduce the percentage of sand in the bed downstream of the structure. As a result, trails are a modification that should be investigated further.

The suspended sediment samples collected during this study show that the suspended sediment concentration has reduced since 1937. This would indicate a potential decrease in the rate of land accretion around regulating structures, thus indicating a potential decrease in the rate of loss of aquatic habitat. However, there are many regulating structures that have been added in the river since 1937.

Analyzing the water surface area and wetted edge data obtained from the four sub-areas shows, for three of the four sub-areas, that the loss rate between 1970 and 1980 is less than the loss rate between 1965 and 1970. This tends to substantiate the above statement concerning suspended sediment.

The location of a structure, with respect to the thalweg, appears to influence the gradation and accretion pattern associated with regulating structures more than the type or location of modification. In other words, a dike or dike field located on the outside of a bend in the river will be subjected to different flow patterns and velocities than one that is located on the inside of the bend.

The point velocity data collected during this study indicates that there is a correlation between the flow pattern downstream of regulating structures and the gradation of accreted material and accretion pattern.

A similarity in scour pattern does exist immediately downstream of all dikes. However, analysis of the lateral bed profiles and bed contour plots will show that a notch in a river regulating structure produces its own scour hole immediately downstream of the notch. It is believed that the size and shape of this scour hole might be related to the size and shape of the notch. As a result, this is a parameter that should be investigated further.

Analysis of the data collected with the recording fathometer revealed that the flow pattern and accretion pattern downstream of a regulating structure are influenced by a notch. There are definite flow channels found in the accreted material that are maintained by flow through the notch. The flow channel configuration and accretion pattern downstream of adjacent notched structures is different from that downstream of a single notched structure.

The rate of change in stage preceding a data collection period appears to influence the bed configuration downstream of regulating structures. In other words, the change taking place immediately

downstream of a channel regulating structure depends upon the duration of flows and the rate of change of the water surface at the structure. To make long-term predictions, data are needed to evaluate the change that occurs after the structure has been subjected to the annual fluctuation of flows.

Based upon this short study period of 140 days and the limited data collected at eight dikes, it is believed that very little bank caving or scouring is taking place in the study reach of the Middle Mississippi River. Most of the scour or deposition occurring downstream of the dikes seems to be coming from the normal bed-load carried by the river which fluctuates with the rise and fall of the flows in the river. Many of the changes noted could be accounted for locally at each dike.

Based upon the data collected during the biological study, diversity of aquatic macroinvertebrates, and to a lesser extent fish communities, was found to be greater at notched dikes than at unnotched dikes. This is believed to be due to the greater variety of habitats created below notched structures. In other words, suitable habitat was available to more species. In addition, the length-frequency analyses of fish indicated that the dissimilar habitat conditions at conventional and modified structures suited different life stages of fish. Selective modification of channel regulating structures in the future on the Middle Mississippi River would make additional,diverse habitats available to greater numbers of the resident fauna.

Fish abundance at conventional and modified dikes did not appear to be significantly different; however, aquatic macroinvertebrates were more abundant at notched dikes. The similar catch rates of fish at each type of dike are believed to be a result of high water and because

many of the species are extremely mobile. Future research should be directed towards species of fish (e.g., gizzard shad, carp, bigmouth buffalo, channel catfish, blue catfish, flathead catfish, and freshwater drum) that are especially important to the recreational and commercial fisheries. Intensive population studies on selected species could determine the population levels that these habitats are capable of supporting.

Individual species of fish and groups of similar fish and aquatic macroinvertebrates exhibited affinities to habitat conditions associated with unnotched and notched dikes. The data collected in this study indicate that suitable habitat exists at each type of dike for many species, but certain characteristics of the habitat accommodate species differently. For example, one year's data indicated that notched dikes were preferred by sturgeons, buffalo, walleye and sauger, caddisflies, and flies and unnotched dikes were preferred by paddlefish, freshwater drum, and aquatic earthworms. Where dikes are necessary to maintain the navigation channel, diverse habitat conditions could be made available. Implementation of a properly planned structure modification program throughout the Middle Mississippi River would have cumulative benefits to fish and invertebrate communities.

Integrated long-term, physical and biological studies of channel regulating structures in the Middle Mississippi River should be conducted to gain a better understanding of the relationship between this habitat and its inhabitants. Future research should attempt to subdivide the habitat at a dike (e.g., dike tip, dike proper, size of rock, pilings, notch, scour hole below a notch, trail dike, revetment, sand shoreline,

mud shoreline, etc.) and determine the value of each subhabitat to the fishery. Properly planned future dike construction and maintenance work could then provide desirable subhabitats.

The previous findings appear to justify the extension of this investigation into a second phase. This seems warranted in light of the fact that many serious questions remain in regard to the impact of structures on fish and wildlife habitat. It is believed by the investigators that a follow-up or in-depth second phase of effort might result in the elimination of some questions and assumptions which could not be addressed in this effort.

Long-term trends in channel geometry and aquatic habitat cannot be established without further investigation. The response of the system to annual variations of flow is needed and can be determined with yearly visits over a period of time.

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